Correlation of Hotspot Isotopic Data with Mantle Tomography

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Isotopic data have been gathered from igneous rocks at areas believed to be hotspots. These data include ratios of $^{208}Pb/^{204}Pb$, $^{206}Pb/^{204}Pb$, $^{207}Pb/^{204}Pb$, $^{87}Sr/^{86}Sr$, and $^{143}Nd/^{144}Nd$. The lead ratios are typically expressed as deviations from the reference lines given by:

$$(^{207}Pb/^{204}Pb)_{NHRL} = 0.1084(^{206}Pb/^{204}Pb)+13.491$$

$$(^{208}Pb/^{204}Pb)_{NHRL} = 1.209(^{206}Pb/^{204}Pb)+15.627$$

The expressions for these deviations are given by:

$$\Delta 7/4 = [(^{207}Pb/^{204}Pb)-(^{207}Pb/^{204}Pb)_{NHRL}]x100$$

$$\Delta 8/4 = [(^{208}Pb/^{204}Pb)-(^{208}Pb/^{204}Pb)_{NHRL}]x100$$

For the strontium and neodymium ratios, the following expressions are used:

$$\Delta Sr = \{[(^{87}Sr/^{86}Sr)-0.7]-[(^{87}Sr/^{86}Sr)_{REF}-0.7]\}x10^4$$

$$\Delta Nd = \{[(^{143}Nd/^{144}Nd)-0.51]-[(^{143}Nd/^{144}Nd)_{REF}-0.51]\}x10^4$$

$$(^{87}Sr/^{86}Sr)REF = .70368$$

$$(^{143}Nd/^{144}Nd)REF = .512907$$

This is the same system for lead used by Hart (1984). The baseline strontium and neodymium ratios, used above, are the median values of the strontium and neodymium isotopic ratios used in this study. The "standard" for strontium is from the Comores hotspot, and the neodymium "standard" is from St. Helena.

All of these isotopes and their parent elements are incompatible, entering melts preferentially, but the important aspects of these elements are their relative incompatibilities. It is expected that melts extracted from primitive mantle material would have higher U/Pb, Th/Pb and Rb/Sr ratios than primitive mantle owing to the greater incompatibility of the parent elements as compared to the daughter elements. Conversely, the higher incompatibility of neodymium as compared to its parent, samarium, would result in a lower Sm/Nd ratio in the melt.

Castillo (1988) claimed that the Dupal anomaly correlated well with low velocity regions in the lower mantle. In addition, all degree except 2 and 3 in the tomography were discarded. This study examines the quantitative significance of this correlation with the lower mantle, and, since the correlation is to be done depth by depth, it should be possible to determine the depths at which these correlations occur. Additionally, correlations in the upper mantle and at other degrees will be found and evaluated.

Procedure: Hart (1981) gives a list of 43 hotspots with all three of the lead ratios listed above and a subset of 37 of these with the strontium ratios. Zindler et al (1982) gives a list of 12 hotspots with the neodymium isotopic data, Gill (1984), Vidal et al (1984), Roden et al (1982) and Richardson et al (1982), bringing the total number of hotspot neodymium data points to 18. The data was then expanded into spherical harmonics to degree 18 using a code developed by Robert Clayton. The data exhibit a spectrally flat signature with only a small possible peak in degree 10 for the lead data. A plot of the 18 degree expansion showed that the expansion becomes invalid prior to degree 18. The Tanimoto (1990) tomography expansion is only available to degree 6, so the higher degrees in the isotopic data are thrown out, resulting in

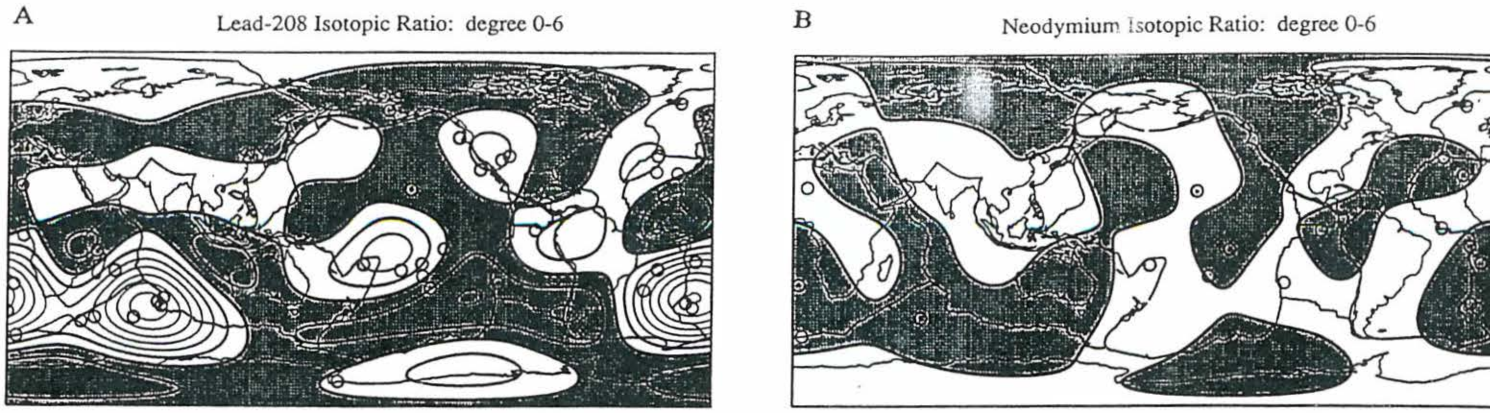

Figure 1: Degree 0 through 6 spherical harmonic expansions of A) Δ8/4 and B) ΔNd. Shaded areas are regions of negative values. Circles show the locations of data points.

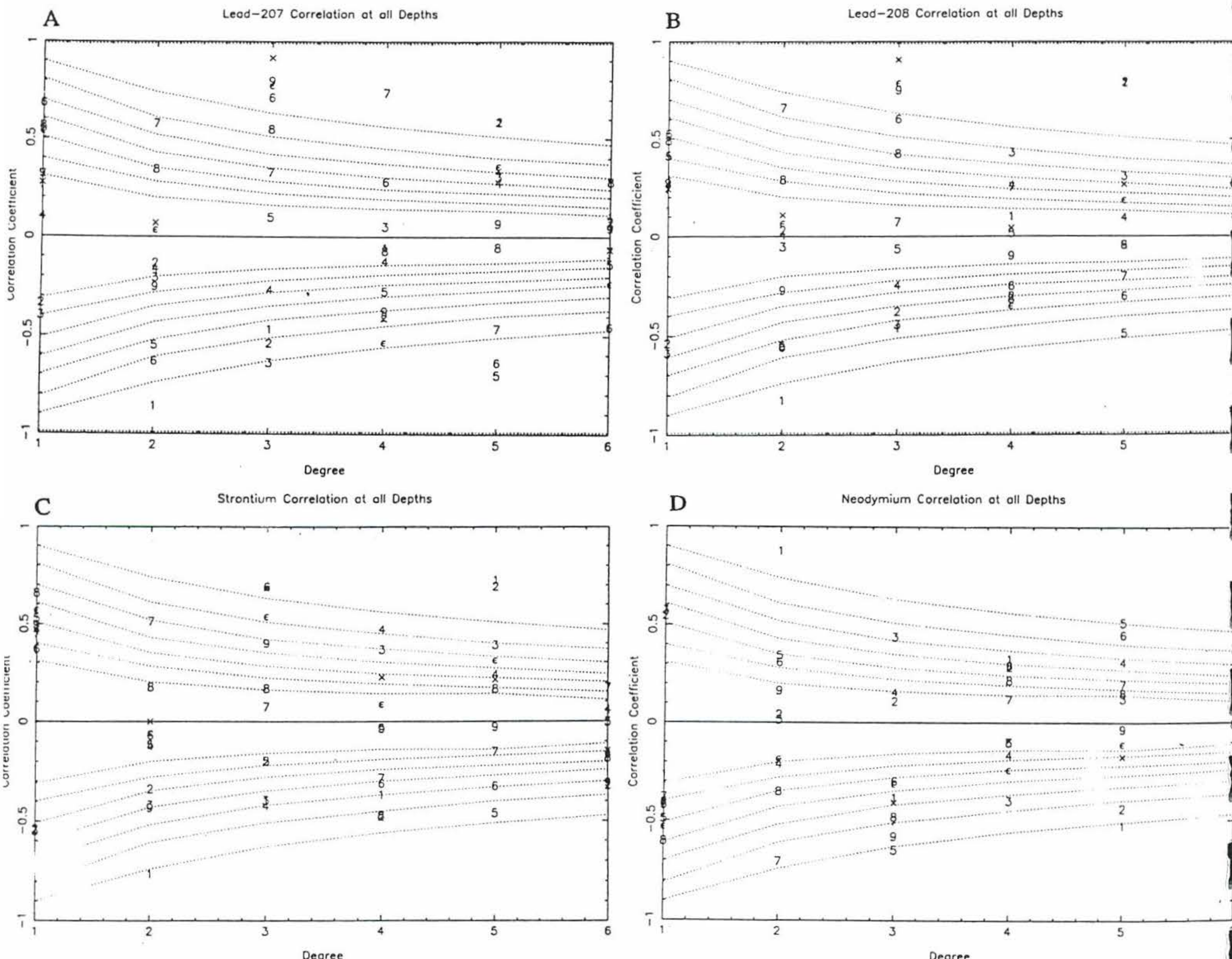

Figure 2: Correlation plots of isotopic values against mantle velocity A) Δ7/4, B) Δ8/4, C) ΔSr, D) ΔNd. Positive correlations represent high isotopic values correlating with slow regions or low values correlating with fast regions. Dotted lines are confidence levels in increments of 10% from 90% to 30%. The numbers indicate the layer of the Tanimoto (1990) tomography at which the correlation is calculated with x representing layer 10 and ε denoting layer 11.

potentially substantial power loss because of the flatness of the power spectra. Figure 1 shows plots of the Δ8/4 and ΔNd expansions through degree 6.

Cross-correlation between the isotopes indicates that the lead isotopes correlate very strongly with each other, and that neodymium and strontium have fairly good anticorrelation. Gerlach (1990) has noted strontium - neodymium anticorrelation and used it to argue for upper mantle heterogeneities. The lead - strontium cross-correlation shows relatively little correlation between the isotopes except for a strong negative correlation in degree 2. Neodymium, on the other hand, has a strong positive correlation with the lead in degree 2 with little correlation elsewhere.

The Tanimoto (1990) tomography model is a model of mantle velocities based on long-wavelength S-waves. There are eleven layers to this model. For convenience, I refer to layers 1 through 3 (0 - 670 km) as the upper mantle, layers 4 through 8 (670 - 2088 km) as the middle mantle, and layers 9 through 11 (2088 - 2891 km) as the lower mantle.

Results: Figure 2 shows plots of the correlation coefficients for each of the four isotopic ratios. First, we see that there are strong correlations between isotopic maps and the lowest part of the mantle (2088 - 2891 km). This is a large scale (degree 3) correlation, and is very strong in the lead isotopes and somewhat weaker in the strontium and neodymium isotopes. This suggests that some large scale deep mantle structure may control the geochemical composition of magmas erupted at the surface. However, there is a paucity of correlations at any other degree in this region of the mantle.

The near-surface degree 5 isotopic signature seems to correlate quite well with the slow areas in the shallow mantle, consistent with these being reservoirs for erupted magma. The larger-scale correlations in degree 2 in the upper mantle are less easily understood. Further complicating matters in degree 2 is the fact that lead and strontium both correlate positively with upper mantle tomography but anticorrelate with each other. The same problem arises with the negative degree 2 neodymium correlation with the tomography and the positive cross-correlation with lead in that same degree. The relationship of these degree 5 and degree 2 structures in the upper mantle to the degree 3 structure in the lowest part of the mantle is unclear.

The middle portion of the mantle exhibits several scales of structure relating to the isotopic maps. Structures from degree 2 to degree 6 are apparent, which could suggest a bridge from the degree 3 lower mantle structure to the degrees 2 and 5 upper mantle structures. The fact that the degree 2 and degree 5 correlations in the middle mantle are opposite sense of the correlations in the upper mantle gives this idea some difficulty. A strong degree 3 correlation occurs with the lead and strontium isotopes in layer 6 of the tomography (1284 - 1555 km). This correlation is of the same sense as the deep mantle correlation, and may therefore be a shallower expression of the structure in the lowest mantle which correlates with the isotopes. However, with regard to the lead isotopes, the layer 6 correlation is weaker than the lowest mantle correlations, and, except for very weak correlations in layer 8, there are no other degree 3 correlations evident.

Further work in this area needs to be done. There are MORB isotopic data which can be correlated in the same manner both as a separate data set and as part of a combined MORB - hotspot data set. A correlation of these isotopic maps with the geoid could also provide some relations to mantle dynamics and structure. There are also higher resolution tomography maps of the shallow mantle available, and the flat power distribution of the isotopic data suggest that important things may occur at higher degree harmonics.

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